

The role of biotechnology for agricultural sustainability in Africa

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Sub-Saharan Africa could have a shortfall of nearly 90 Mt of cereals by the year 2025 if current agricultural practices are maintained. Biotechnology is one of the ways to improve agricultural production. Insect-resistant varieties of maize and cotton suitable for the subcontinent have been identified as already having a significant impact. Virus-resistant crops are under development. These include maize resistant to the African endemic maize streak virus and cassava resistant to African cassava mosaic virus. Parasitic weeds such as *Striga* attack the roots of crops such as maize, millet, sorghum and upland rice. Field trials in Kenya using a variety of maize resistant to a herbicide have proven very successful. Drought-tolerant crops are also under development as are improved varieties of local African crops such as bananas, cassava, sorghum and sweet potatoes.

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1. INTRODUCTION

Africa is a continent rich in natural and human resources. More than 900 million people live here, two-thirds in small towns and villages scattered throughout rain forests, deserts and vast grasslands. Yet it is also a place where, because of famine, disease and growing populations, almost 200 million people are undernourished and 33 million children go to sleep malnourished and hungry every night. More than 60% of malnourished Africans live in Eastern Africa. Parts of West Africa have shown decreases in the prevalence of malnutrition in recent years (InterAcademy Council 2004).

African agriculture has a unique set of features that make it very different from Asia where the Green Revolution has had a pervasive impact. These include

- lack of a dominant farming system;
- predominance of rainfed agriculture as opposed to irrigation; and
- prevalence of soils of poor fertility.

There is a vast difference between farming practices on the fields of a farmer growing just one of two different crops to another growing a range of crops on less than one hectare in Africa. The former will use varieties developed from highly inbred lines and adapted to relevant climate. The latter, often a woman, will grow many different crops that minimize her risk of failure. For example, she might plant some maize and beans in case rainfall is plentiful, and perhaps some sorghum, cassava and cowpea in case of drought. Cost considerations will prevent her from using even marginally acceptable levels of fertilizer or pesticides. These differences almost guarantee that any

crop bred in the 'North' will not be adapted to her growing conditions (Delmer 2005).

Although 17 distinct farming systems have been identified in Africa, four show the most promise for increasing agricultural outputs. These are

- the maize-mixed system, based primarily on maize, cotton, cattle, goats, poultry and off-farm work;
- the cereal/root crop-mixed system, based primarily on maize, sorghum, millet, cassava, yams, legumes and cattle;
- the irrigated system, based primarily on rice, cotton, vegetables, rainfed crops, cattle and poultry; and
- the tree crop-based system, based primarily on cocoa, coffee, palm, rubber, yams, maize and off-farm work (InterAcademy Council 2004).

One of the greatest challenges today for Africa is to improve the nutrient status of agricultural lands, many of which are acidic, low in phosphorous and high in toxic aluminium. Some soils are naturally richer in nutrients than others and can be exploited for a while. Eventually, however, they lose nutrients that have to be replaced. Without nutrient replacement, there is no agricultural sustainability. African farmers cannot, on the whole, afford synthetic nutrients. Productivity is often low, which reduces the amount of organic material available to be returned to the soil after harvesting. It is therefore imperative to increase the amount of organic matter grown in African soil (Thomson 2002).

In Africa, crop production per unit of land cultivated is the lowest in the agricultural world. Florence Wambugu (1999) cites the example of sweet potato, a staple crop on parts of the continent. The yields are approximately 6 t ha^{-1} compared with the global average of 14 t ha^{-1} . There is the potential for African production to double if soil fertility could be improved and viral diseases controlled (Wambugu 1999).

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Table 1. Projected cereal yields and production in 2025 by region. (Adapted from Dyson (1999).)

region	average area harvested, 1989–1991 (Mha)	projected production on the basis of constant area (Mt)	shortfall/surplus compared with projected demand (Mt)
sub-Saharan Africa	59.3	91.1	–88.7
the Middle East	40.2	99.2	–132.7
South Asia	140.3	524.6	–25.1
East and Southeast Asia	145.1	914.0	–126.9
Latin America	48.4	171.2	–46.7
Europe/FSU ^a	171.4	619.4	+112.9
North America/Oceania	98.4	558.2	+238.7

^a Former Soviet Union.

In 1999, Tim Dyson published an article entitled ‘World food trends and prospects to 2025’. In it, he states: ‘Despite fears to the contrary, in recent years we have seen continued progress toward better methods of feeding humanity. Sub-Saharan Africa is the sole major exception’. His projected cereal yields and shortfalls/surpluses by the year 2025 are given in table 1.

How will the regions with large projected shortfalls cope? The Middle East will depend more on cereal imports, perhaps to the extent of meeting 50% of its requirement. Most countries in the region are likely to be able to finance most of their imports. China as well as East and Southeast Asia are likely to increase their imports significantly, but China’s performance in raising cereal yields has been, and continues to be, strong. Sub-Saharan Africa, in contrast, is unlikely to see much improvement in its overall food situation. It is highly unlikely that cereal imports, including food aid, will increase to anywhere near the requirement in 2025. Only a minority of countries will be able to afford to buy sizable amounts of food. What, therefore, can be done to improve the agricultural productivity?

The question of how to feed poor people in developing countries was addressed at a meeting in 2001. It was held under the auspices of the International Food Policy Research Institute (IFPRI) and entitled Sustainable Food Security for All by 2020 (IFPRI 2002). A very interesting paper was delivered by the Minister of Agriculture from Uganda, and I suspect what he had to say can apply to many African countries. In Uganda, women account for 80% of the labour force in agriculture. Therefore, any improvements in agriculture must focus on their needs, and one of the primary ones is their low status compared with men. Thus, any agricultural project or programme must involve women from the very beginning. Women also need leisure, so any technology that relieves them of time-consuming farm tasks is important.

Among the interventions suggested was the use of modern biotechnology. This includes tissue culture, marker-assisted breeding, biological control and genetic modification. This article will concentrate on the role of biotechnology, mainly, but not exclusively, through the use of genetic modification, in achieving sustainable agriculture for Africa.

In 2003, the United Nations Industrial Development Organization (UNIDO) convened a meeting in Nairobi to address the question of which biotechnological interventions were most important to Africa. Agricultural experts from around the continent

approached the problems with their eyes on two objectives. Firstly, what interventions are readily available for adaptation to Africa, and secondly, what are the most pressing problems even if the solutions lay some years in the future.

The list, not in any particular order, was:

- insect-resistant African maize varieties expressing one of the *Bacillus thuringiensis* (*Bt*) *cry* genes coding for insect-specific toxins;
- crops resistant to African viruses such as the *maize streak virus* (MSV) and the *African cassava mosaic virus* (ACMV);
- maize resistant to the parasitic weed, *Striga*
- decreased levels of mycotoxins in maize, which may be possible due to diminished post-harvest fungal infection in *Bt* maize varieties; and
- drought-tolerant crops.

I will consider each of these, and a few others, in this paper. In addition, I will address some of the biotechnological interventions being supported by the African Agricultural Foundation (AATF). This Foundation, based in Nairobi, was launched in June 2004. It is a private not-for-profit organization dedicated to increasing the productivity of resource-poor farmers in sub-Saharan Africa by providing them with greater access to proprietary agricultural technologies and know-how. It aims to define the constraints of the region’s smallholder farmers and identify opportunities to address those constraints through the royalty-free transfer and use of new and existing proprietary technologies (www.aatf-africa.org).

2. INSECT-RESISTANT AFRICAN MAIZE VARIETIES EXPRESSING ONE OF THE *BACILLUS THURINGIENSIS* (*BT*) *CRY* GENES CODING FOR INSECT-SPECIFIC TOXINS

Maize is one of the most important sources of calories for the poor in Africa, second only to cassava. It forms a significant part of the diets of millions of smallholder subsistence farmers, who grow it primarily in mixed cropping systems. Small- to medium-scale farmers, who cultivate 10 ha or less, grow 95% of the maize produced in Africa. Stem borers cause significant yield losses in all African ecosystems where the crop is grown. Losses range from 15 to 40%, but when conditions favour insect infestation, total crop failure can occur (AATF 2005).

Table 2. Estimated area planted to transgenic maize in hectares and total crop percentage (Gouse *et al.* 2005).

	1999/2000	2000/2001	2001/2002	2002/2003
yellow maize	50 000 3	75 000 5	160 000 14	197 000 20
white maize	0 0	0 0	6000 0.4	55 000 2.8
total <i>Bt</i> maize	50 000 1.3	75 000 2.3	166 000 4.7	252 000 7.1

Table 3. Yields of GM crops (1000 ha) in RSA from 2000 to 2005 (W. Green 2005, personal communication).

crop	2000	2001	2002	2003	2004	2005 (estimated)
<i>Bt</i> maize (white)	not planted	4	61	155	233	308
<i>Bt</i> maize (yellow)	77	125	109	170	210	205
<i>Bt</i> cotton	18	25	24	39	25	30
herbicide-resistant soya beans	not planted	not planted	13	45	50	60
total	95	154	207	409	520	603

Insect-resistant genetically modified maize, expressing the *Bacillus thuringiensis* (*Bt*) toxin, has been commercialized only in RSA, where it is grown both by small-scale and commercial farmers. Yellow maize is primarily used for cattle feed and in the food industry, in products such as corn starch and syrup. *Bt* yellow maize has been on the market since 1998, but *Bt* white maize has only been available commercially since 2001. The use and uptake of genetically modified (GM) maize varieties could be an important case study to determine whether GM crops can benefit commercial farmers as well as small-scale farmers and poor consumers.

The early stages of adoption of GM maize were slow. By the 2002/2003 season, 20% of yellow maize but only 2.8% of white maize was *Bt*. There were three major constraints that slowed the spread of *Bt* maize. The first was that the *Bt* hybrids on the market were not the best for African markets or agricultural conditions. The second was that many farmers did not see a large productivity advantage from planting *Bt* maize as planting strategies can mitigate against the stalk borer in areas other than those most affected by the pest. In addition, different types of borers show different levels of sensitivity to the *Bt* toxin. This can also vary between indigenous and introduced insect species. The third reason was farmers' concerns that they would not be able to sell their crop due to consumer concerns about GM food (Gouse *et al.* 2005).

This started to change in 2000 and 2001 with the introduction of yellow maize hybrids specifically developed for RSA's dry windy conditions. In addition, in 2001/2002 borers were a serious problem for commercial farmers. This led to increased demand for *Bt* maize in 2002/2003. And finally farmers did not have any difficulty in selling their GM crops. Indeed, in a recent study, Paarlberg (2006) found that most African countries would not experience problems in exporting agricultural products even if they planted GM crops. As a combined result of these factors, the demand for GM maize increased (table 2). Indeed, the major constraint may be the supply of seed, especially white maize, which is not keeping up with the demand.

The yields of GM crops from 2000 to 2005 are shown in table 3. *Bt* cotton and herbicide-resistant soya beans are included for comparison.

Most of the plantings of *Bt* yellow and white maize in RSA are by large-scale farmers. Small-scale farmers who plant maize for home consumption plant only white maize. A limited number of them plant *Bt* yellow maize to feed to animals. Although a few small-scale farmers have planted *Bt* white maize, commercial farmers bought almost all the limited supply of this seed in 2002/2003.

Bt seeds are sold at a premium of SAR230 per 60 000 seeds (US\$35 at an exchange rate—which can be quite volatile—of 6.5). The top-of-the-line conventional hybrids sell at R850–900 meaning that commercial farmers buying these lines will pay a surcharge of 20–21%. Lowest-quality maize sells at SAR650 per 60 000 seeds meaning that small-scale farmers buying this will pay a surcharge of 26%. They will therefore have to show considerable profit to continue to plant *Bt* maize. Time will tell if this is the case.

Currently commercial farmers who have planted *Bt* yellow maize have seen an increase in their income compared with their conventional maize fields, despite paying the technology fee. As they received the same price for their *Bt* maize and their conventional maize, the difference was directly due to the yield increase. They were also able to reduce their costs by reducing the amount of pesticide applied. The increase in net income ranged from US\$24 ha⁻¹ in dry land areas to US\$143 ha⁻¹ in irrigated regions (Gouse *et al.* 2005).

Can small-scale farmers benefit from *Bt* white maize? With price differentials of \$83 kg⁻¹ *Bt* maize seed compared with \$52 kg⁻¹ for non-*Bt* seed, the answer is probably no, unless the farmers already buy hybrid maize. It is estimated that only 10% of small-scale farmers use hybrid seeds, the rest planting open-pollinated varieties and saved seeds of open-pollinated varieties. These are varieties bred specifically to allow farmers to replant seeds for a limited number of seasons before buying fresh seed again. None of these varieties have been genetically modified, largely because the profit margins are very low. However, there may be

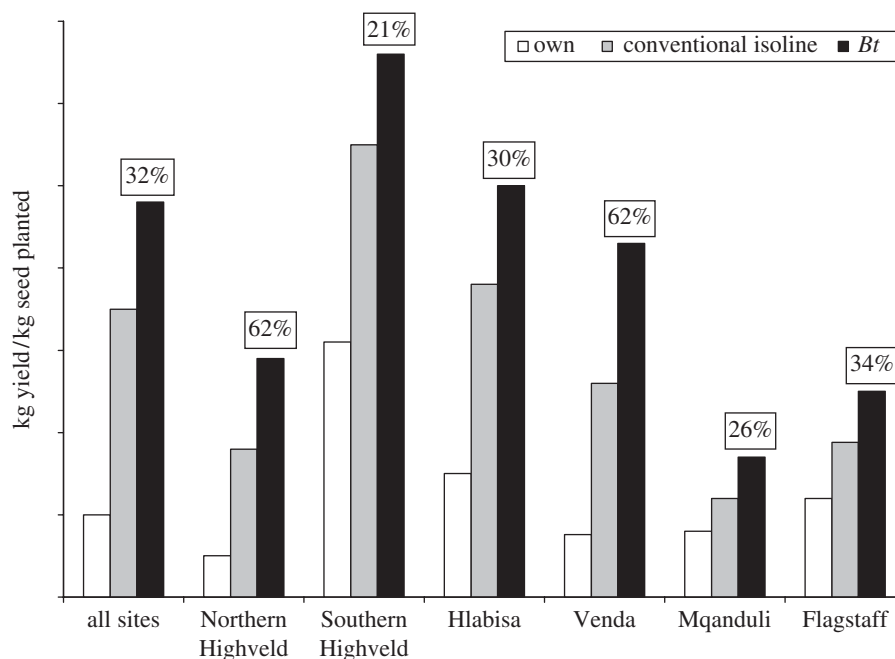


Figure 1. Small-scale farmers' yields per kilogram of seed, by seed type for six sites in 2001/2002 (Gouse *et al.* 2005).

more opportunities for the adoption of *Bt* white maize by small-scale farmers elsewhere in Africa where many have already adopted hybrids. These countries include Zimbabwe where 91% of the maize area was hybrid, Kenya with 85% and Zambia with 65% in 1997–1999 (Pingali 2001).

A survey was conducted among 368 small-scale farmers in six sites in RSA during the 2001/2002 growing season (Gouse *et al.* 2005). The evidence suggests that *Bt* maize has potential benefits for such farmers (figure 1). Another important finding was that the farmers also liked the quality of the maize produced by the *Bt* variety, Yieldgard. At harvest, farmers were shown their own seed, seed from the same variety as the *Bt* maize but without the *Bt* gene, and Yieldgard. They were asked to judge the grain according to quality. 'The majority of farmers rated Yieldgard grain to be of excellent quality, while many farmers rated the (other) grains as good quality. When asked what they liked best about the *Bt* hybrid maize, farmers at three sites chose better quality, while higher yield was the most important reason at the other three sites. The farmers did not put much importance on the benefits from pesticide reduction (probably because only half of them used pesticides).' Whether poor farmers unable to afford pesticides will be prepared to pay extra for hybrid *Bt* maize remains to be seen.

Can *Bt* maize spread to a larger share of small-scale farmers in RSA? One solution would be for seed companies to charge a lower technology fee to these farmers compared with commercial farmers. One company is already doing this with conventional hybrid maize seed. Another way would be for private–public partnerships to introduce the *Bt* gene into open-pollinated varieties. This would enable small-scale farmers to save their seed and still get the benefit of *Bt*. However, it would be impossible for the government to enforce any type of *Bt* maize refuge plantings. As such plantings delay the onset of the evolution of *Bt*-resistant stem borers, this could increase the speed

at which resistant insects develop. Thus, until we know more about the development of resistance, this possibility is probably not a realistic option (Gouse *et al.* 2005).

It is important that the biosafety regulatory process does not make it more expensive to provide *Bt* maize to small-scale farmers. Under the current system in RSA, the companies that sell GM seeds must sign a contract with every farmer to ensure s(he) plants the seed in the designated area and abides by the proper refuge requirements. They are required to plant 20% of their *Bt* area with non-*Bt* hybrids if they spray the refuges with pesticides, or 5% if they do not. This is relatively easy for large companies who sell directly through their marketing agents to large commercial farmers. However, this is an expensive requirement when companies are dealing with thousands of small-scale farmers and could well lead to a decision not to sell GM seeds to them at all.

To bring insect-resistant maize to the rest of Africa, a consortium is undertaking a project entitled IRMA (Insect-Resistant Maize for Africa). This aims to provide sub-Saharan Africa smallholder maize producers with access to suitable *Bt* maize varieties that are resistant to the major stem borers that limit maize productivity in the region. A combination of traditional plant breeding and genetic modification is being used in this project.

An alternative to *Bt* maize is to plant crops that will attract insect borers. One example is the use of Napier grass, pioneered by Kenya's International Centre for Insect Physiology and Ecology. Rows of Napier grass planted around a maize field will attract up to 70% of egg-laying moths, depending on the ratio of maize to Napier grass.

3. INSECT-RESISTANT COTTON

Although this was not highlighted as a priority for African agriculture at the 2003 UNIDO meeting, cotton is still an important crop for some countries

Table 4. Cotton yields, revenue and costs per hectare for adopters and non-adopters of *Bt* cotton in RSA (Morse *et al.* 2004).

output (kg) and costs (SAR/ha)	1998/1999		1999/2000		2000/2001	
	non-adopters (<i>n</i> = 1196)	adopters (<i>n</i> = 7)	non-adopters (<i>n</i> = 329)	adopters (<i>n</i> = 112)	non-adopters (<i>n</i> = 254)	adopters (<i>n</i> = 245)
yield	452	738	264	489	501	783
total revenue	984	1605	574	1064	1090	1704
seed cost	138	278	190	413	176	260
pesticide cost	153	72	222	104	305	113
spray labour cost	77	38	108	49	135	45
harvest labour cost	113	184	66	122	125	196
gross margin	502	1033	−11	376	348	1090
gross margin gain in US\$ based on exchange rate at harvest	86		59		93	

on the continent, including RSA and Egypt, the two most involved in the development and release of GM crops. Insect attack is one of the major constraints to cotton cultivation worldwide and the yield losses account for an estimated \$5 billion annually. Approximately 25% of all insecticides used in agriculture are applied to cotton, more than to any other crop (James 2004). This percentage can reach staggering proportions, as high as 80% in some Central and West African countries (James 2002a–c).

Scientists at the University of Reading in the UK have been weighing the economic costs and benefits of *Bt* cotton in RSA for a number of years (Ismael *et al.* 2001; Morse *et al.* 2003). Seeds for this crop were released commercially in 1997 and have been grown since then rather extensively by small-scale farmers in the Makhathini Flats area of KwaZulu-Natal near the border with Mozambique. They estimated that by the 2001/2002 growing season, 90% of the farmers in this region were growing *Bt* cotton. Many of the main insecticides used here are highly toxic, and carrying a knapsack sprayer for many hours is tiring and dangerous to human health. Smallholder farmers, half of whom are women, receive a 77% higher return on cotton. In general, the smaller the farm, the greater the benefits received.

However, as the authors note, one does need to keep benefits in perspective. *Bt* cotton is not a magic bullet that will solve poverty among these farmers overnight. The highest gross advantage per hectare was found to be approximately SAR 700 which translates into approximately US\$88 ha^{−1}, depending on the rather volatile SAR exchange rate. The agricultural wage rates in the Makhathini Flats are approximately \$1 d^{−1}. Therefore, the advantage of growing *Bt* cotton is at best equivalent to approximately 15–18 days paid employment in a city—provided, of course, one is able to travel to the city and obtain work there. This is not an easy option in rural RSA today. Therefore, if *Bt* cotton is managed properly to ensure continued productivity, it can be a positive and potentially sustainable contribution to farmers in the part of RSA.

In a follow-up paper (Morse *et al.* 2004), the authors comment that their analysis of the ‘economic impacts of the uptake of *Bt* cotton by resource-poor, smallholder farmers in RSA [i]s the first such study on the continent of Africa based on farmers’ own practice as distinct from

field-trial data collected under controlled conditions. To our knowledge, there have been no comparable and large-scale studies on the continent of Africa and few anywhere that look at *Bt* cotton production under entirely farmer-managed conditions’.

They state that *Bt* cotton adopters achieved consistently higher yields and revenue per hectare than non-adopters over the three seasons 1998/1999, 1999/2000 and 2000/2001. This was particularly noticeable in the poor, wet growing season of 1999/2000, which favoured bollworm. Adopters had higher seed costs due to the *Bt* seed premium, but lower pesticide costs, both in product procurement and the use of labour for spraying. However, due to the higher yields achieved by the *Bt* adopters their costs of harvesting, due to increased use of labour, were significantly higher. This shows that the concerns of labour unions that the use of *Bt* cotton will result in the decrease of labour employed are unfounded.

The result of all these differences between *Bt* cotton adopters and non-adopters is that the former achieved substantially higher gross margins across all three seasons. In financial terms, this advantage amounted to approximately R531–742 (approximately equal to US\$76–106 at an exchange rate of 6.5) per hectare on average (table 3). ‘In the 1999/2000 wet season, those growing non-*Bt* cotton actually had a negative gross margin, which resulted in them have difficulty paying back credit that they had borrowed.’

In Egypt, the Agricultural Genetic Engineering Research Institute in collaboration with Monsanto has developed an insect-resistant long-staple GM cotton strain by crossing Egyptian elite germ plasm with Monsanto’s Bollgard II. Egyptian cotton is known as one of the world’s finest and is the country’s most important agricultural export (table 4).

4. CROPS RESISTANT TO AFRICAN VIRUSES SUCH AS MSV AND THE ACMV

Africa is home to a number of serious plant viruses such as MSV and ACMV. Indeed, a few years ago, Uganda nearly lost its entire crop of cassava (manioc) to the latter virus and ACMV is now spreading rapidly towards Nigeria, one of Africa’s most important producers of the crop.

Breeders in Africa have succeeded in developing MSV-resistant varieties of maize, but the resistance

often breaks down due to the development of more virulent virus strains. In addition, varieties bred for resistance in one African country are often not effective in others due to environmental and other conditions. It would therefore be advantageous to develop a GM maize line with a single gene conferring MSV resistance. This could then be crossed into regionally important commercial varieties.

My laboratory, together with that of Prof. EP Rybicki, has been involved in developing such maize plants. Unlike most plant viruses, MSV has DNA, not RNA, as its genetic material. For a variety of reasons, the introduction of the coat protein gene, which is usually used to develop virus-resistant crops, are unlikely to protect a plant against infection from a DNA virus. In fact, this has been tried with MSV and no protection was afforded. We have therefore used the gene for another MSV protein, one involved in its replication, to develop transgenic virus-resistant maize.

When MSV, which is transmitted by the leafhopper, *Cicadulina mbila*, infects a maize plant, the first gene to be expressed codes for the replication-associated protein (Rep). These proteins form a multimer which binds to a hairpin loop in the viral origin of replication. This complex initiates rolling circle replication and the viral DNA is subsequently replicated using host replication proteins. We have developed transgenic lines which express constitutive high levels of a mutated, truncated form of the Rep. The protein has a number of domains that are essential for viral replication. These have been mutated and the gene truncated to retain essentially only these domains plus that required for multimer formation. Transgenic plants have been subjected to extremely high levels of MSV infection in glass house trials. The results are extremely promising and the plants appear to be immune to MSV infection. Field trials are planned for the near future.

Cassava mosaic disease (CMD), caused by ACMV, is the most important constraint to the production of cassava in Africa (Legg & Fauquet 2004). A severe epidemic of CMD spread through Uganda in the 1990s causing losses valued at more than US\$60 million annually between 1992 and 1997. Farmers abandoned the crop in many parts of the country, resulting in food shortages. Later in the 1990s, the epidemic spread to Sudan, Kenya, Tanzania and the Democratic Republic of Congo. Since then, the disease has been managed to some extent by phytosanitation, comprising all the techniques that can keep plants in a virus-free condition. This includes removal of CMD-affected plants from within a field and the selection of symptom-free cassava stems for planting. There has also been some success in breeding ACMV-resistant cultivars. However, the problem persists and scientists are developing GM lines of ACMV-resistant cassava. As with MSV, ACMV is a DNA virus and scientists are using a variety of strategies to develop crop resistance. Initial results are very promising (Chellappan *et al.* 2004).

Sweet potatoes are subject to some devastating viruses in parts of East and central Africa. The most prevalent sweet potato virus disease is caused by a mixed infection of *sweet potato chlorotic stunt* and *sweet potato feathery mottle viruses*. The former might even

have a synergistic effect on the latter, increasing its concentration in the plants. The gene of viral coat proteins was transformed into sweet potatoes and the resultant GM plants field tested in Nairobi. They appear not to have been successful, possibly because the coat protein genes were not from the most virulent viruses in the region. The work is ongoing.

5. MAIZE RESISTANT TO THE PARASITIC WEED *STRIGA*

Striga spp. (witchweed) are killers in many sub-Saharan African countries. These aggressive parasitic weeds attack the roots of crops such as maize, millet, sorghum and upland rice, and steal nutrients from them. As the roots of *Striga* become intertwined with the roots of the plant, the weeds are almost impossible to remove by conventional weeding, unless this is performed almost as soon as the weeds appear above ground. *Striga* infests as much as 40 Mha of smallholder farmland in the region and causes losses ranging from 20% in a normal year to as much as 80% under severe infestation. It affects the livelihoods of more than 100 million people, causing annual crop losses estimated to be worth \$1 billion.

Field trials in Kenya using a non-GM maize variety resistant to the herbicide, imazapyr (StrigAway), have proven very successful. The maize seeds are coated with the weedkiller. When the weeds attack the developing roots, they are rapidly killed leaving the maize healthy. Yield increases ranging from 38 to 82% compared with traditional varieties have been reported in the field trials. Technology transfer is being negotiated by the AATF (2005).

Another approach is being pioneered by a Japanese group working with colleagues in the Sudan (Akiyama *et al.* 2005). *Striga* plants produce thousands of tiny seeds which lie dormant in the soil until a host plant, such as maize, begins to germinate. This plant releases transesquiterpene compounds that signal the *Striga* seeds to germinate. Once this occurs, the weeds immediately attack the host plant. That is why many farmers abandon a field, or are forced to cultivate non-*Striga* host plants, once it has been infected with *Striga*. The Japanese group hopes to purify the relevant compound(s) and use it(them) to artificially stimulate the *Striga* seeds to germinate in the absence of a host plant. As *Striga* relies on its host for a significant proportion of its nutrients, the weeds would die.

6. DECREASED LEVELS OF MYCOTOXINS IN MAIZE

The vast majority of maize consumed by humans in the developed world is either milled, processed or purchased as 'corn-on-the-cob'. In the former two cases, the products are subjected to food safety tests, and in the latter, mere inspection by the purchaser is sufficient to ensure quality. However, this is not the case with consumers in the developing world. A subsistence maize farmer in Africa will harvest the crop and may then store it year round for consumption by the family and possibly close neighbours. The maize is usually stored in roofless structures where it can be rained upon and the sun can shine upon it. If the maize

has been attacked by insects that bore into the ears, the holes provided, together with the moist, warm conditions, provide the ideal breeding ground for fungi. These will cause rotting of the ears, but more importantly, they can produce life-threatening toxins. These mycotoxins include fumonisins, produced by *Fusarium* spp., and aflatoxins, produced by *Aspergillus* spp., among others (Marasas 2001). The effects of these mycotoxins have on humans include oesophageal cancer, liver cancer and neural tube defects (Hendricks 1999; Wang *et al.* 2003).

It is possible that insect-resistant maize could help to decrease these fungal infections. Most of the studies have been carried out in Europe where it was found that over a number of years *Bt* maize consistently decreased the level of fumonisin (Munkvold *et al.* 1999). On average, there was more than a sixfold decrease in levels (see James 2002a–c). *Bt* maize allowed the levels of mycotoxins to be lowered to below the acceptable levels of 2 ppm compared with the levels of 9 ppm in conventional maize. The latter is almost five times higher than the acceptable guidance levels specified by the World Health Organization. The effect of *Bt* maize on the prevalence of mycotoxins in stored maize in Africa awaits further study, but it would appear that this crop could enhance the quality and safety of maize for animal and human consumption (Marasas & Vismer 2003). However, much of the post-harvest damage of stored maize could be caused by insects not targeted by the specific *Bt* toxin. In that case, storage practices need to be improved.

7. DROUGHT-TOLERANT CROPS

Water is a major limiting factor in world agriculture with most crops being highly sensitive to even mild dehydration. It is estimated that one-third of the 1.5 billion hectares of the world's arable land is affected by drought (James 2002a–c). Many research groups are working on the development of crops such as maize and wheat that are tolerant to drought. Although drought-tolerant crops are still very much in the development stages, their importance to Africa is so great that they are included here.

A research team at the University of Cape Town, including my laboratory, is using genes isolated from a South African indigenous 'resurrection plant', *Xerophyta viscosa*, to develop drought-tolerant maize. Resurrection plants are unique in that they are able to tolerate almost complete desiccation. They can lose 95% of their water content and remain in a dormant stage, looking completely dead, for months on end. Upon the addition of water, the plants can literally 'resurrect' in a matter of days.

The resurrection plant on which we work is found growing in cracks in rocks in the Drakensberg mountains in the KwaZulu-Natal province of RSA. The plants therefore grow with very little soil which can rapidly dry out. In addition, day-time temperatures are often as high as 40°C, while the night-time temperatures can drop to below freezing. We postulated that these plants must have some very interesting genes coding for very interesting proteins to enable them to flourish in this environment.

Among the genes we have isolated are the ones coding for proteins that protect the plant cell from water loss by replacing the water with sugars such as sorbitol. Others bind to the cell membrane and probably act to detect dehydration stress and signal to the interior of the cell that other genes must be 'switched on' to produce proteins to protect the cell. Some of the latter proteins act as anti-oxidants to protect the DNA and other molecules in the cell from damage (Mundree *et al.* 2002).

One of the genes we have tested codes for an aldose reductase that converts glucose to sorbitol, a known osmoprotectant (Mundree *et al.* 2000). Transgenic plants showed tolerance to dehydration and salinity stresses. Another encodes a stress-responsive membrane-binding protein with no significant similarity to any proteins in the databases (Garwe *et al.* 2003). Transgenic plants showed tolerance to dehydration as well as salinity and heat stresses. Further trials are underway.

A number of researchers have shown that the accumulation of the sugar trehalose confers resistance to a number of abiotic stresses in transgenic rice (Garg *et al.* 2002; Jang *et al.* 2003). The sugar helps stabilize biological molecules and protects against tissue damage during dehydration. Garg *et al.* plan to seek patent protection for the modification and will ensure public availability of the modified crop to farmers in developing countries (Nuffield 2004).

8. LOCAL AFRICAN CROPS

A number of initiatives in Africa are aimed at developing improved varieties of local crops and although these were not highlighted at the UNIDO meeting, they are included in this paper due to their local importance. The crops include bananas, cassava, cowpea, sorghum and sweet potatoes. It is clear that multinational companies have little interest in improving yields of these crops; therefore, Africans have to produce them for themselves.

(a) Bananas

Bananas and plantains are major food sources for a number of African countries. There are two major types of varieties used as staple foods: the east African highland bananas, which produce mainly cooking (matoke) and 'beer' bananas in Uganda, and the plantains, mainly found in the lowlands of west and central Africa. The productivity of bananas and plantains in sub-Saharan Africa is severely constrained by a range of pests and diseases including nematodes, banana bacterial wilt, banana weevils, the fungus *Fusarium* spp. and the bacteria known as black Sigatoka that causes leaf spot (AATF 2005). A number of laboratories within and outside Africa are working on solving some of these problems.

Florence Wambugu has spearheaded the use of tissue culture for improving banana production in Kenya (Wambugu 2001). The traditional way of propagating bananas is to uproot a young sucker from around the base of a mature plant. Although this is very cheap and easy, it has the disadvantage of carrying over pests and diseases. Tissue culture breaks this cycle of infestation as it involves the production of fresh

material under sterile conditions in a laboratory. The use of juvenile tissues and hormones in the culture media are further sources of plant vigour. In addition, when improved varieties, derived by conventional breeding, are propagated, the process of tissue culture leads to plants that mature earlier and yield more than conventionally propagated ones. The use of these plants can transform a smallholder's banana orchard from one that barely meets subsistence needs to farms that provide produce to the markets of Kenya and beyond.

I visited some banana farmers near Nairobi in June 2004 and was extremely impressed by their yields of healthy fruit. I was told that the increased income generated by the new varieties had changed the status of the crop from being a 'woman's crop' to becoming a 'man's crop'. The difference is that 'women's crops' feed their families but 'men's crops' make money.

(b) *Cassava*

Cassava is a very hardy root crop which serves as a major subsistence staple in sub-Saharan Africa. It is also an important cash crop for many smallholder farmers in the region, and it plays a key role during times of famine. Unlike other major food crops, cassava is tolerant to poor soils and adverse weather conditions. The carbohydrate yield from cassava per unit of land is higher than for other major staples; it thrives across a wide range of ecological zones. It is normally available all year round, thus contributing to household food security. However, its roots, which represent its most economically valuable part, have poor keeping qualities and must be processed within 3 days (AATF 2005).

In her 2005 paper, Deborah Delmer describes a meeting that brought together bench and field scientists at which breeders told molecular biologists that cassava flowers poorly and that two varieties needed for a cross often did not flower at the same time in the same breeding station. 'From this emerged a project to attempt to create cassava for breeding purposes that has a flower-inducing gene under the control of an ethanol-inducible promoter.'

In addition, the Bill and Melinda Gates Foundation is funding the development of nutritionally enhanced GM cassava under the so-called 'BioCassava Plus' project. The cassava will have higher vitamin A and E levels. This is very important as cassava feeds 40% of Africa's population.

(c) *Cowpea*

Cowpea is the most important food grain legume in the dry savannas of tropical Africa, where it covers more than 12.5 Mha. It is rich in high-quality protein and contains almost as much energy by weight as cereal grains. Cowpea is consumed by nearly 200 million African. It provides cash income to smallholder farmers, serves as nutritional fodder for livestock and provides an ideal way to complement protein-deficient diets. Unfortunately, cowpea productivity in traditional African farming systems is greatly reduced by biotic and abiotic stresses (AATF 2005).

Research is underway at various African and other research institutions under the umbrella of the Network for the Genetic Improvement of Cowpea in Africa to develop improved varieties of cowpea. The aims are

to develop varieties that perform better in the face of these stresses, have higher yield potential and have even greater nutritional value. One of the major insect pests is the *Maruca* pod borer. The AATF is negotiating with Monsanto for the use of the *cry1Ab*, whose product confers resistance to *Maruca*. Cowpea transformation has been established by scientists at the CSIRO in Canberra, Australia.

(d) *Sorghum*

A very important initiative was announced recently—the Africa Biofortified Sorghum Project (http://www.supersorghum.org/fact_abs.htm), also dubbed 'The SuperSorghum Project'. It brings together nine institutions, seven in Africa and two in the USA and is a truly public/private partnership. It strengthens the recent report by the IFPRI that public research institutions in Africa are conducting 'ground-breaking' research on GM crops (<http://www.ifpri.org/media/20050707afbiotech.asp>). The traits being introduced include provitamin A, vitamin E, zinc, iron and lysine.

9. CONCLUSIONS

One solution to the improvement of agriculture in Africa has been outlined by Delmer (2005). She proposes that the model for public-private partnerships (PPP) could be based on the fact that development of beneficial traits such as disease and pest resistance, or drought tolerance, in major crops may best be addressed by the private sector, whereas the public sector holds a wide range of locally adapted germ plasm relevant to poor farmers. 'In such a PPP, the public sector supports efforts to transfer valuable private-sector traits/genes into a range of locally adapted varieties suitable for low-input agriculture, with the private sector concentrating on varieties that would be sold in the larger, more profitable, markets of large-scale farmers.' However, for the crops such as cowpea, sweet potatoes, bananas, cassava and sorghum, mentioned above, the burden for crop improvement will fall to the public sector, although the private sector should be strongly encouraged to find ways to share relevant technologies and provide crucial advice.

Many people say enough food is produced in the world to feed everyone. However, people have been saying this for decades and we still have shortages. One of the problems is distribution; how do we get food to the people in need? Certainly, we should stop wars, eliminate corruption so that food gets to the right people, build roads and rails to transport food, but how long will that take? In the meantime, GM crops that give increased yields are just one of the ways in which we can tackle the problem.

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